International Comparison of Energy Efficiency (Lighting in the Residential and Commercial Sector)

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Overview of lighting source technologies, energy saving and barriers in lighting and international comparison of energy efficiency in lighting

1. Lighting source technologies

(1) Introduction

Luminaires are required not only to provide physical illuminance but also to assure other application needs such as color rendering, amenity and artistic design qualities. Accordingly, it is crucial to keep the glare off and to control light and dark contrast on some occasions. We focus on technological elements of lighting sources rather than not at overall luminaries and their cultural aspects.

As common lighting sources, incandescent and fluorescent lights have been historically used but recently LED (light emitting diode) and OLED (organic light emitting diode) lights have attracted attention. The followings are summaries of characteristics and technological trends of lighting source.

(2) Incandescent lamps

Incandescent bulbs utilize light emission through exothermic Joule heating. They are inexpensive and excellent at color rendering properties*, but short-lived (1,000 hours for common bulbs) and their energy efficiencies are low[1]. Tungsten is commonly used as a filament material and argon gas is commonly used to fill up bulbs.

*Color rendering properties/index; a quantitative measure of the color reproduction ability of a light source in comparison with an ideal or natural light source. There are often differences between the numerical assessment (Ra: general color rendering index) and the subjective color rendering performance judged by human eyes [2].

<u>Types of incandescent lights (cost/life range) [1]</u>

1. Common bulbs (JPY90–JPY150/1,000 hours)
2. Ball bulbs (JPY190–JPY250/2,000 hours) … often used for decorative illumination
3. Mini krypton bulbs (JPY190–JPY250/2,000 hours) … arc lamps filled with krypton; most of them are small type

4. Halogen lamps (JPY2,000–JPY25,000/3,000 hours) ... an incandescent lamp in which a tungsten filament is sealed into a compact transparent envelope filled with an inert gas and a small amount of halogen, used for spotlights, down lights, studio lighting, and car headlights

The price data above is based on Japanese retail prices of April 2007, and the life range is based on the reference [1]; the same data and reference are used below.

Characteristics of common incandescent lights

Advantage:	Inexpensive
Advantage:	Excellent at color rendering
Advantage:	Fast switching time, reaching to 100% brightness in 0.1 or 0.2 seconds
Advantage:	Dimmer controllable
Advantage:	Applicable at hot and humid locations (e.g. outdoors, bathrooms, washstands)
Disadvantage:	Short lifetime in general (longer lifetime at the sacrifice of energy efficiency)
Disadvantage:	Low energy efficiency

(3) Fluorescent lamps

A fluorescent lamp is an arc-discharge lamp that uses electricity to excite mercury vapor atoms. The excited mercury atoms emit short-wavelength (253.7nm) ultraviolet light that then collide with fluorescent material, producing visible light. A fluorescent lamp converts electrical power into visible light more efficiently and has a longer lifetime than an incandescent lamp, which consumes a quarter of energy that an incandescent lamp dose.

Costs of 40W linear fluorescent lamps by starting type

1. Manual starting
2. Glow tube starting (FL)(JPY180–JPY750: warm white or 3-wavelength types are expensive)…what is called a “starter type”, consisting of a fluorescent lamp tube, ballast and glow tube starter. Conventional glow tube starters take 3 seconds to light up
3. Rapid starting (FLR)(JPY160–JPY500: warm white or 3-wavelength types are expensive)… starting with a magnetic leakage flux transformer, without a glow starter

4. High-frequency start (Hf, FHF) (JPY440–JPY880): “a high-frequency inverter”, the DC transmitted in rectifying circuits, converted to high-frequency AC by inverters to light up/mainly for household use

Costs by shape

1. Compact fluorescent bulbs (JPY950–JPY1200)… available as direct substitutes for incandecent lamps, fitting existing incandescent lamp fixtures
2. Compact fluorescent lamps [(JPY800–JPY2000) depending on the wattage] The above two types are called CFL (compact fluorescent lamp)
3. Linear fluorescent lamps (refer to the cost above)… a stick type, mainly for commercial uses (e.g. office)
4. Ring-type fluorescent lamps (40W common type: JPY400–JPY800, 40W slim type: JPY1000–JPY1200)… mainly for household use; slim types of higher efficiency are available

General characteristics of fluorescent lamps

Disadvantage: Initial costs are high but totally more economic than incadescent lamps when applied for a few years
Medium: Low color rendering in general, but some are improved
Disadvantage: Frequent on and off switching causes lamps to age relatively fast
Medium: Some types are available for dimmer controls
Disadvantage: Unsuitable for hot and humid locations
Advantage: Long lifetime in general
Advantage: High energy efficiency

(4) HID: High intensity discharge lamps

High intensity discharge lamps produce light by means of arc discharge in high-pressure atomic metal vapor. High intensity discharge lamps include high pressure sodium lamps, metal halide lamp, and a high-pressure mercury lamps. They are often applied to wide a space, since their simple structures make it easy and economical to produce large size lamps. Generally, HID lamps have high energy efficiency, long lifetime and excellent color rendering. Particularly, they have been used in factories, outdoor grounds or courts, gyms/halls/showrooms and streets, as well as for headlights of cars and railcars.

General characteristics of high intensity discharge lamps

Medium: Small lamps are expensive but large lamps are economical judging from costs per unit light flux

Advantage: Relatively excellent at color rendering

Disadvantage: Frequent switching on and off causes lamps to age rapidly/ it takes a few minutes for light flux to be stable.

Medium: Ballasts are necessary to control light emission for high pressure sodium lamps and high-pressure mercury lamps. Metal halide lamps can not be dimmer-controlled.

Advantage: Long lifetime in general

Advantage: High energy efficiency

(5) LED: Light emitting diodes

LEDs had luminous efficacy 30–40 lumens per watt [lm/W] in October 2005. The efficacy between those of an incandescent lamp and a fluorescent lamp is demonstrated in the commercial use. However, LEDs have potentials to reach 100 lumens per watt in a few years [3]. LEDs have some advantages including compact and lightweight, visibility, fast switching, high anti-seismicity and long lifetime (a few tens of thousands of hours), but they are relatively low at luminescense intensity and expensive at present. Thanks to the above advantages, they have been applied as to traffic lights, compact lighting, night-lights, emergency guide lights and decorative lighting (e.g. neon signs)[4].

<u>General characteristics of LEDs</u>

Disadvantage: Expensive, but economical from a long-term perspective due to long lifetime and high efficiency

Advantage: Excellent at visibility

Advantage: Fast switching time

Advantage: High energy efficiency

Disadvantage: Not appropriate for wide area/ bright lighting, but high potential/perspective to increase in application for car headlights in the future)

Advantage: High technological improvement potentials in future

(6) OLED: Organic light emitting diode

Organic light emitting diodes consists of a transparent top substrate, transparent anode, conductive layer of electron holes, light emissive layer, conductive layer of electrons, cathode and bottom substrate. The conductive layer of electron holes and the emissive layer are made of organic material, diamine and anthracene, respectively, and they are called organic LEDs. Electric current flows from the cathode to the anode through the organic layers, while electron holes and electron emit photos in the emissive layer. Light source itself has a characteristic of 2-dimentional spread, and this allows commercial application for compact and relatively short lifetime products such as cellphone displays. Larger size, longer lifetime and lower cost are required to commercialize OLEDs for common light sources or thin displays.

<u>General characteristics of OLEDs</u>

Disadvantage:	Expensive
Medium:	Short lifetime in general (2,000–10,000 hours lifetime is achieved by the latest technological development)
Advantage:	High energy efficiency (the light source itself is flat and the energy efficiency is good)
Disadvantage:	Not appropriate for wide area/ bright lighting
Advantage:	High potentials of substantial technological improvement in future
Advantage:	High potentials to be developed to extremely thin and fodable device

IEA(2006a) has very useful data, summarizing the latest data including lighting source technologies mentioned above[3]. However, the rapid progress of lighting source technologies is remarkable and we need to pay attention to that the above information is based on only the current situation. For example, compact fluorescent bulbs/compact fluorescent lamps (CFL) are sold at about JPY100 in China, and LEDs, which are considered expensive at present, are becoming inexpensive rapidly. Consequently, these lamps have potentials to be commonly used as standard light sources at an early stage.

2. Energy-saving methods and barriers in lighting

Using sunlight effectively may lead to reduce lighting demand substantially. Please refer to [5] for more details about historical changes in lighting, and IEA(2006b)[6] and IPCC(2007)[7] about the latest measures. The reference[6], [7] specifically introduce doors for sunlight introduction, automated blinds integrated with lighting control equip, passive sunlight collecting systems (equipments to transmit visible light into buildings inside using aluminum pipes with coated surface), etc.

Electricity consumption for lighting can be reduced by improving lighting fixture layout, such as ‘task/ambient lighting’. A simple but effective strategy to further reduce enegy use is to provide a relatively low background lighting level, with local necessary illumination at individual workstations(IPCC(2007) [7] p.402). Energy use also can be effectively saved to reduce unnecessary lighting fixtures and over lighting.

However, there are some barriers to measures to save lighting energy. One of them is that the costs are not minimized in the whole lighting systems, including initial costs and running costs of lighting fixtures and daylight application, since split-incentive among achitects, daylight designers, installers of lighting fixtures and running cost payers (users of the buildings).

On the other hand, in some non-OECD countries, electricity prices are regulated to below for reasons of improvement of energy access (e.g. susidizing electricity tariffs) and incandescent lamps are given to their people for free by the governments. Another barrier is that CFLs (Compact fluorescent bulbs/lamps) have potentials to be alternatives of incandescent lamps and have been commoly produced and distributed in developing countries too, but poor quality CFLs that have short lifetime may worsen their reputations. Furthermore, the lifetime of fluorescent lamps depends on the electricity quality (voltage stability, for example) through grids and in some regions where the quality is not good enough, and there is still trend toward incandescent lamps. These are other barriers that hinder energy saving in lighting[3].

3. International comparison of energy efficiency

Since the available data are limited, it is difficult to have correct figures of lighting fixtures and use, especially in developing countries. We conducted an estimation in our way, referring to ‘Average lighting-system efficacy by region in 2005 (lm/W)’, ‘estimated per capita consumptiion of electric light in 2005 (Mlmh)’ IEA(2006a)[3], and to make up insufficient data for minor regions, ‘the relationship between per capita GDP and lighting demand’ IEA(2007)[8], and electricity consumption in household and commercial sector of IEA’s Energy balances are used.

The folowing sectors which are fewer than those of IEA(2006a)[3] are considered in our estimation of lighting demand.

Included sectors for lighting demand estimation

- General lighting in residential and commercial sector
- General lighting in government/public office sector
- Outdoor/road sector

Excluded applications(sectors) for lighting demand estimation

- Industrial sector (plants, storage buildings)
- Special lighting (e.g. tunnels)
- Lighting by private power generation (not through grids) and by stolen electricity through grids
- Lighting by non-electricity (lamp oil, firewood)
- Lighting of vehicles (cars, trains)

Table 1 shows estimated regional lighting demand, lighting efficacy and electricity consumption.

Table 1 Estimated regional lighting demand, lighting efficacy and electricity consumption of 2000

	Light consumption (Tlmh/yr)	Lighting electricity consumption (TWh/yr)	Average lamp efficacy (lm/W)
United States	21,304	428	49.7
Canada	1,801	36	50.3
EU 15	12,417	241	51.6
Other Western Europe*	430	8	51.2
East Europe**	2,276	49	46.7
Japan	5,384	88	61.2
Korea	1,779	30	58.9
Australia/New Zealand	1,028	21	49.5
China	6,048	113	53.6
India	2,358	55	42.9
Other Asia	4,149	95	43.7
Middle East	3,776	89	42.3
Turkey	907	21	42.5
Africa	3,584	84	42.7
Mexico	1,463	35	42.3
Brazil	3,949	93	42.4
Other Central and South America	3,809	90	42.6
Former Soviet Union	6,161	149	41.4
World total, average	82,623	1,724	47.9

* Other Western Europe: Norway, Iceland, Switzerland, Malta, etc.

** East Europe: Hungary, Poland, Czech, Bulgaria, Romania, Slovakia, Croatia, Slovenia, Yugoslavia, Albania, Bosnia, etc.

Per-capita lighting demand is great in North America, Europe, Japan and Russia. The demand itself is relatively small as compared to the population, in China, India, Africa, and South America, which implies substantial increases are anticipated in the future for these countries. The average efficacy is higher in Japan and Korea, as well as China where the increase in lighting demand is remarkable nowadays.

4. Summary

Lighting source technologies, energy saving measures and barriers in lighting and international comparison of energy efficiency in lighting are discussed. Advances in lighting source technologies and price reduction are being significant and such trends are considered to continue in the future.

There are a number of energy-saving measures for lighting and the measures have potentials to further advance. Whereas in implementation of energy saving, there are several barriers as mentioned above, higher income will induce lighting demand increasing all the more on a global scale (through improved energy access and advanced tertiary industries). Higher energy efficiency of lighting sources may also induce so called rebound effect, which depends largely on the level of electricity retail prices.

Consequently, comprehensive approach is required to advance true energy savings, including removal of barriers and determination of the level of electricity retail prices from the long-term perspective (e.g. termination of subsidies, introduction of additional tax), as well as diffusion of high efficiency devices.

Reference

[1] The Illuminating Engineering Institute of Japan. http://www.ieij.or.jp/english/

[2] Toli online. http://www.toli.co.jp/m_library/m_library8_15_2.html (in Japanese)

[3] IEA (2006a). Light's labor's lost, Policies for energy-efficient lighting, In support of the G8 Plan of Action, 2006.

[4] Japan LED Association (2006). LED lighting handbook 2006. (in Japanese)

[5] Japan Solar Energy Society (2000). New Solar Energy Utilization Handbook, pp.510-516. (in Japanese)

[6] IEA (2006b). Energy Technology Perspective.

[7] IPCC (2007). Climate Change 2007 - Mitigation of Climate Change: Working Group III contribution to the Fourth Assessment Report of the IPCC.

[8] IEA (2007). Energy balances of OECD/Non-OECD countries, CD-ROM.